$\{V_1(1)\}$) and one assumes the starting time is $\gamma_0=0$. Then, the system evolves as follows.

[0151] 1) From $\gamma_0=0$ to $\gamma_1=15$, task sequence $<y_{20}\rightarrow$robot waits in $q_{02}\rightarrow s_{02}\rightarrow t_{01}\rightarrow s_{11}>$ such that $M_1=(\{W_1(1)\}, \{W_0(1)\}, \{W_0(2)\}, \{W_0(1)\})$ is reached.

[0152] 2) From $\gamma_1=15$ to $\gamma_2=30$, task sequence $<y_{14}\rightarrow$robot waits in $q_{42}\rightarrow s_{42}\rightarrow t_{40}\rightarrow s_{01}>$ such that $M_2=(\{W_1(1)\}, \{V_0(1)\}, \{V_0(2)\}, \{null\})$ is reached.

[0153] 3) From $\gamma_2=30$ to $\gamma_3=42$, task sequence $<y_{03}\rightarrow$robot waits in $q_{32}\rightarrow s_{32}\rightarrow t_{34}\rightarrow s_{41}>$ such that $M_3=(\{W_1(1)\}, \{V_0(1)\}, \{null\}, \{V_0(1)\})$ is reached.

[0154] 4) From $\gamma_3=42$ to $\gamma_4=54$, task sequence $<y_{42}\rightarrow$robot waits in $q_{22}\rightarrow s_{22}\rightarrow t_{23}\rightarrow s_{31}>$ such that $M_4=(\{W_1(1)\}, \{null\}, \{V_0(1)\}, \{V_0(1)\})$ is reached.

[0155] 5) From $\gamma_4=54$ to $\gamma_5=108$, task sequence $<y_{33}\rightarrow$robot waits at step $3\rightarrow s_{32}\rightarrow t_{32}\rightarrow s_{21}>$ such that $M_5=(\{W_1(1)\}, \{V_0(2)\}, \{null\}, \{V_0(1)\})$ is reached.

[0156] 6) From $\gamma_5=108$ to $\gamma_6=157$, task sequence $<y_{22}\rightarrow$robot waits at step $2\rightarrow s_{22}\rightarrow t_{23}\rightarrow s_{31}>$ such that $M_6=(\{W_1(1)\}, \{null\}, \{V_0(2)\}, \{V_0(1)\})$ is reached.

[0157] 7) From $\gamma_6=157$ to $\gamma_7=169$, task sequence $<y_{31}\rightarrow$robot waits in $q_{12}\rightarrow s_{12}\rightarrow t_{12}\rightarrow s_{21}>$ such that $M_7=(\{null\}, \{W_1(1)\}, \{V_0(2)\}, \{V_0(1)\})$ is reached.

[0158] Through the above sequence, a cycle of the system is formed, which demonstrates that the cycle time is 169 s.

[0159] The embodiments disclosed herein may be implemented using general purpose or specialized computing devices, computer processors, or electronic circuitries including but not limited to digital signal processors (DSP), application specific integrated circuits (ASIC), field programmable gate arrays (FPGA), and other programmable logic devices configured or programmed according to the teachings of the present disclosure. Computer instructions or software codes running in the general purpose or specialized computing devices, computer processors, or programmable logic devices can readily be prepared by practitioners skilled in the software or electronic art based on the teachings of the present disclosure.

[0160] In some embodiments, the present invention includes computer storage media having computer instructions or software codes stored therein which can be used to program computers or microprocessors to perform any of the processes of the present invention. The storage media can include, but is not limited to, floppy disks, optical discs, Blu-ray Disc, DVD, CD-ROMs, and magneto-optical disks, ROMs, RAMs, flash memory devices, or any type of media or devices suitable for storing instructions, codes, and/or data.

[0161] The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A computer-implemented method for scheduling a cluster tool, the cluster tool comprising a single-arm robot for wafer handling, a wafer-processing system comprising four process modules including PM_1, PM_2, PM_3, and PM_4, each for performing a wafer-processing step with a wafer residency time constraint where the ith process module, $i\in\{1, 2, \ldots, 4\}$, is used for performing Step i of the wafer-processing steps for each wafer, and a wafer flow pattern having $(PM_1, (PM_2, PM_3)^h, PM_4)$ with $(PM_2, PM_3)^h$ being the revisiting process and $h\geq2$, the method comprising:

obtaining, by a processor, a lower bound z_{iL} of a production cycle of Step i, $i\in\{1, 2, \ldots, 4\}$, as follows:

$$\pi_{1L}=\alpha_1+3\mu+4\lambda;$$

$$\pi_{2L}=2\alpha_2+\alpha_3+5\mu+8\lambda;$$

$$\pi_{3L}=2\alpha_3+\alpha_2+5\mu+8\lambda; \text{ and}$$

$$\pi_{4L}=\alpha_4+3\mu+4\lambda;$$

obtaining, by a processor, an upper bound π_{iU} of a production cycle of Step i, $i\in\{1, 2, \ldots, 4\}$, as follows:

$$\pi_{1U}=\alpha_1+3\mu+4\lambda;$$

$$\pi_{2U}=2\alpha_2+\alpha_3+5\mu+8\lambda;$$

$$\pi_{3U}=2\alpha_3+\alpha_2+5\mu+8\lambda; \text{ and}$$

$$\pi_{4U}=\alpha_4+3\mu+4\lambda;$$

obtaining, by a processor, a maximum lower bound π_{Lmax} as follows:

$$\pi_{Lmax}=\max\{\pi_{iL}, i\in\mathbb{N}_4\};$$

obtaining, by a processor, a minimum upper bound π_{Umin} as follows:

$$\pi_{Umin}=\min\{\pi_{iU}, i\in\mathbb{N}_4\};$$

determining, by a processor, a robot task time η_1 in a cycle as follows:

$$\eta_1=14\lambda+12\mu+\alpha_2+\alpha_3;$$

determining, by a processor, a robot waiting time ω_i of Step i as follows:

if $[\pi_{1L},\pi_{1U}]\cap[\pi_{2L},\pi_{2U}]\cap[\pi_{3L},\pi_{3U}]\cap[\pi_{4L},\pi_{4U}]\neq\emptyset$ and $\eta_1<\pi_{Lmax}$, then setting $\omega_0=\omega_1=\omega_2=\omega_3=0$, and setting $\omega_4=\pi_{Lmax}-\eta_1$;

else if $[\pi_{1L},\pi_{1U}]\cap[\pi_{2L},\pi_{2U}]\cap[\pi_{3L},\pi_{3U}]\cap[\pi_{4L},\pi_{4U}]\neq\emptyset$ and $\pi_{Lmax}\leq\eta_1\leq\pi_{Umin}$, then setting $\omega_0=\omega_1=\omega_2=\omega_3=0$;

else if $[\pi_{1L},\pi_{1U}]\cap[\pi_{2L},\pi_{2U}]\cap[\pi_{3L},\pi_{3U}]\cap[\pi_{4L},\pi_{4U}]=\emptyset$ and $\pi_{Lmax}\leq\eta_1\leq\pi_{Umin}$, then setting $\omega_i, i\in\Omega_3$ by

$$\omega_{i-1}=\begin{cases}0, & i\in F\\ \pi_{Lmax}-\alpha_i-\delta_i-4\lambda-3\mu, & i\in E\cap\{1,4\}\\ \pi_{Lmax}-2\alpha_2-\delta_2-\alpha_3-5\mu-8\lambda, & i\in E\cap\{2\}\\ \pi_{Lmax}-2\alpha_3-\delta_3-\alpha_2-5\mu-8\lambda, & i\in E\cap\{3\}\end{cases}$$

and setting $\omega_4=\pi_{Lmax}-\eta_1-\sum_{i=0}^{3}\omega_i$;

wherein:

α_i, $i\in\mathbb{N}_4$, is a time that a wafer is processed in the ith process module;

δ_i $i\in\mathbb{N}_4$, is a longest time that a wafer stays in the ith process module after being processed;

λ is a time that a wafer is loaded or unloaded by the robot from Step i;